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An Intelligent Knowledge-Based Tutoring System for a Transponder Test Set

Larry Somers
Microexpert Systems, Inc.

for

Contracting Officer's Representative
Joseph Psotka

Technologies for Skill Acquisition & Retention
Technical Area
Zita M. Simutis, Chief

Training Research Laboratory
Jack H. Hiller, Director

U. S. Army
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EDGAR M. JOHNSON
Technical Director

WM. DARRYL HENDERSON
COL, IN
Commanding

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This research note describes the development of an "Intelligent Knowledge-Based Instructional System (IKIS), a portable, pc-based tutor for training operators of the Teledyne AN/APM 424 transponder test set. The system consists of a high-fidelity simulation of the functional operations of the test set, together with mechanisms for teaching cognitive, situational, and procedural components of skills in operation and fault identification at the flight line level of operations. The IKIS demonstrates the basic components required of an intelligent tutoring system, including a knowledge base, an inference engine, a student model, a tutoring strategy, and a well-defined interface for user/system transactions. The report also discusses strategies for the further development and refinement of the knowledge representation approach, student modelling, and instructional strategies and methods.

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SUMMARY

The Intelligent Knowledge-based Instructional System (IKIS) is IBM PC based software designed to teach operator skills for a piece of complex electronic test equipment. This report summarizes preliminary research and development which utilizes simulation as an important component of the learning process. Simulating real world stimulus situations in an adaptive learning environment provides a mechanism for teaching cognitive, situational, and procedural components that semantic knowledge alone can not provide.

Phase I of the IKIS project has produced the basic architecture required for further research and system development of adaptive simulation based training software. The Teledyne Transponder Test Set, a device used to test aircraft transponders on the flight line, served as the subject domain during Phase I. All major system components have been created providing a test bed environment for adding deeper levels of knowledge and increased adaptability during later development. The following report describes each of these components in detail and relates this research with further research and development being proposed for the Phase II effort.

Long term goals of the IKIS project focus on the development of simulation based adaptive tutoring to improve cognitive and behavioral learner performance of real-time tasks. The modular design of the Phase I system architecture provides for the ability to add and modify system components rapidly in an iterative fashion. Because of this further research and development, Phase II can build on Phase I results but is not limited by the Phase I environment.

Methods for teaching knowledge which integrates many cognitive and behavioral components is a subject which still requires theoretical research. Developing intelligent tutoring systems that adapt to individual learners and can model the learning process effectively is a related area also of some theoretical research. Combining research and development in these related areas will be essential for cost effective and efficient operator training on the increasingly sophisticated equipment currently being developed for use in both military and industrial applications. This research will have major impacts in training throughout the public and private sector. Hence, the IKIS project provides a developmental tool that can be useful in advancing research in these areas, as well as a product that can have immediate use for the Army and the corporate sponsor.

PREFACE

The research described in this report is authorized under contract number MDA903-87-C-0585 issued by Department of the Army Defense Supply Service-Washington.

The report describes worked completed for Phase I of a three phase U.S. Department of Defense SBIR research project. It relates the work completed with work to be done in Phase II and Phase III of this project.

MICROEXPERT Systems is greatly indebted to the Teledyne Electronics Company and especially Mr. John Taylor. Without the generous help and information they provided this research would not have been possible.

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INTRODUCTION

IKIS, an Intelligent Knowledge-based Instructional System, is a project designed to provide research and development for an intelligent tutoring system. The IKIS project seeks to encode the expertise of a teacher and technician combined with high fidelity simulation to improve cognitive and behavioral performance of the learner. The following report describes the results of Phase I research and development of IKIS and its relationship to future Phase II and Phase III efforts.

PROJECT GOALS

The Phase I contract has two major goals related to the development of an Intelligent Tutoring System. They are :

* A complete systems design and specification

* A demonstration program to prove feasibility

Within the framework of the project several subgoals were identified:

* Design a "friendly" graphics oriented user interface.

* Develop a test bed environment for investigation of student behavioral measurements

* Investigate the components needed for further development of an Intelligent Tutor Authoring System.

* Utilize a high resolution simulation

* Design for field portable and embedded training

PROJECT PROCEDURAL PLAN

The Phase I project plan emphasized rapidly prototyping the major modules needed in an Intelligent Tutor. This would provide an iterative test bed environment for adding, testing, and revising heuristics and metaknowledge during Phase II.

A diagram indicating the project development is shown in Figure 1 below.

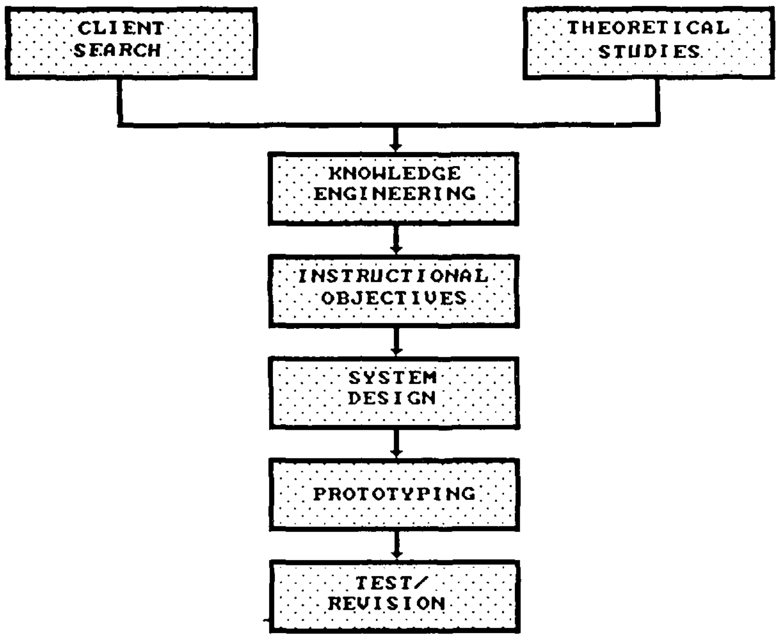

Figure 1. Project development

PROJECT OVERVIEW

SUBJECT DOMAIN SEARCH

Early project design decisions suggested developing a tutoring system that would adapt itself easily to a variety of subject matter. This would create an authoring tool whose usefulness goes beyond the initial project goals. When completed, IKIS will be an authoring system that allows instructional experts to develop a variety of instructional applications easily.

In choosing the subject domain, the main criteria included:

* Benefits for the corporate sponsor as well as Army goals
* Subject matter applicable to high fidelity simulation
* Access to domain expertise
* Required effort commensurate with Phase I funding

After consultation with several potential corporate sponsors, it was determined that for Phase I operator training on the Teledyne AN/APM-424(v)2 Transponder Test would serve as the subject domain. The Transponder Test Set is a hand held device that the Army has recently chosen to purchase for testing aircraft IFF (Identification Friend or Foe) transponders on the flight line. The cognitive learning tasks related to overall operation of this device are important and non-trivial in size and content. Training of operators in the field is currently limited to an instruction manual. There is no team or classroom teaching.

Operation of the Test Set requires the operator to integrate procedural and factual relationships of test set and transponder operation with transponder and test set fault identification, plus deeper knowledge related to IFF theory. Operators who have attempted to learn from only the manual have reported frustration in understanding the functions and relationships of the component parts. According to Teledyne instructors, field technicians are likely not to read the instruction manual but instead to attempt to teach themselves by trial and error experimentation with the test set. It is likely that this type of learning will result in the incomplete and inaccurate formation of important cognitive relationships. Furthermore it could result in damage to the test set and/or reduce readiness if working aircraft are diagnosed as faulty due to incorrect test set operation.

The subject domain lends itself well to a high fidelity simulation as part of the instructional design. Both Army field technicians and the corporate sponsor benefit from development of the product. The long range development of an authoring system for designing simulation based intelligent tutoring systems will have broad applications for training in both the public and private sectors.

HARDWARE TRADEOFF

A subgoal of the project was to make IKIS field portable. Teledyne Electronics utilizes primarily IBM compatible microcomputers. Thus the designer chose an IBM compatible microcomputer to be the developmental system. The minimum configuration required to fulfill the project goals and objectives include:

* Minimum 640 Kilobytes RAM memory
* 20 megabyte hard disk
* EGA color graphics capability

In addition, some additional features are desirable:

* 80286 or 80386 microprocessor
* 4 megabyte RAM

SOFTWARE TRADEOFF

A major objective of Phase I was to develop a rapid prototype designed to demonstrate proof of concept and serve as a test bed environment for iterative testing of teaching strategies, simulation, heuristical inferencing and the user interface.

The goals required a language with:

* Modular code
* High resolution color graphics capability
* Mouse and windowing routines built in
* High level for rapid prototyping

A number of expert systems shells, including M.1 (Teknowledge) and Rulemaster (Radian), were found to be limited in their graphics

capability and built in heuristical support. Implementations of LISP on the PC also were rejected, as they lack strong graphics and windowing routines, required longer prototyping times, and lacked mouse input routines. For similar reasons languages such as C and Pascal were ruled out.

The language chosen to fit both software and hardware requirements of Phase I was Smalltalk V, recently released by Digitalk Inc. It provides EGA color graphics capabilities, windowing and mouse routines.It is object oriented and produces modular code. These capabilities suggested the ability to develop a rapid prototype of the proposed system design. Once the original design is complete, changes and additions can easily be made in order to test out new ideas and refinements to the project. Furthermore the modular nature of this object oriented language provides an incremental method of recoding to improve system execution during later phases of the project.

SYSTEM OVERVIEW

For the Phase I SBIR contract MICROEXPERT Systems, Inc., created IKIS, an Intelligent Knowledge-Based Instructional System, for operator field training on the Teledyne AN/APM-424(v)2 Transponder Test Set.

The Test Set is hand held electronic test equipment used by field technicians to test aircraft transponders on the flight line. The Test Set is housed in a metal box approximately 1.5 cubic feet in volume with a battery pack on the bottom, a handle with test buttons on the side, and a flat antenna on top. It has a viewfinder through which the technician can aim at an aircraft's antenna and read test results on a display.

IKIS demonstrates the major components of a simulation based intelligent tutoring systems and serves as a test bed for further development in this field. The IKIS Phase I prototype utilizes high fidelity graphics to simulate the operation of the Transponder Test Set, along with a Socratic style tutor and coach to assist the learning process. It demonstrates the major components required of an intelligent tutoring system including an inference engine and knowledge base, a student model, a tutoring strategy, and a friendly user interface.

The user interacts with IKIS primarily through the use of a mouse pointing device with some input through the keyboard. Interactive components of IKIS are shown in different windows on the computer display. Four major window are available to the user: the Test Set, Tutor, Viewfinder, and Test Zones windows.

The Test Set window, shown in Figure 2, gives the user an outside view of the Test Set and provides pop-up menus for simulating the connections the user makes between the Test Set, KIR-1 computer and power supply. It further simulates the steps the user must go through when loading secret codes into the computer for use by the Test Set.

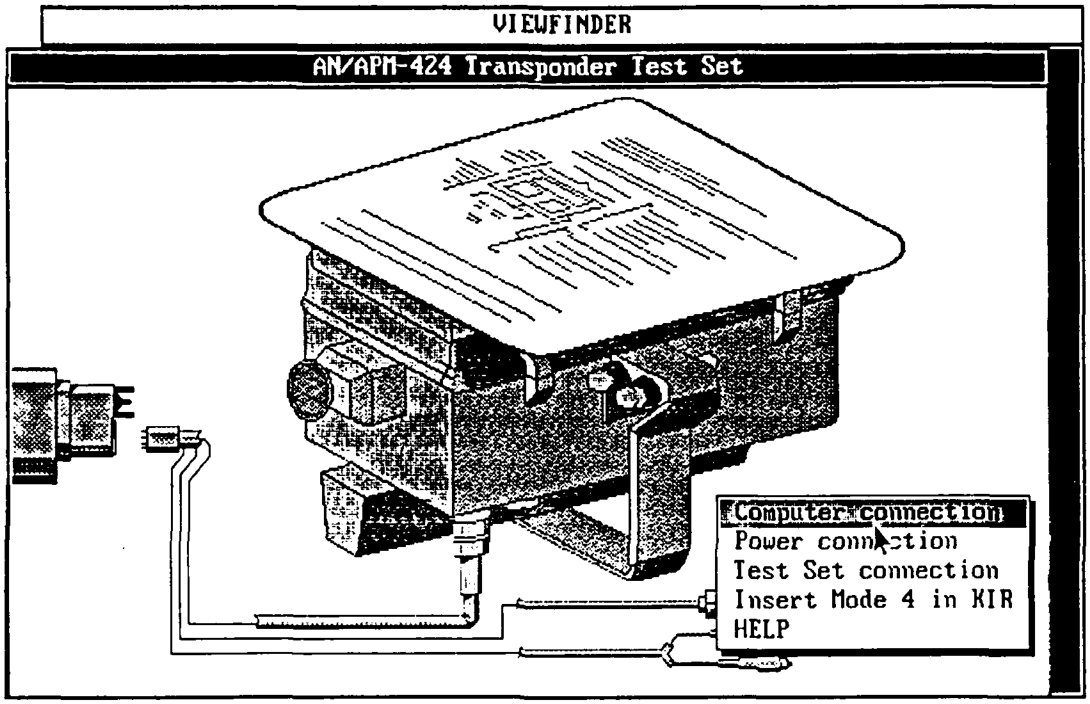

Figure 2. Transponder test set window

Simulation of the Test Set includes a view through the Test Set Viewfinder. The viewfinder window is shown in Figure 3.

Basic operation of the Test Set involves looking through the Viewfinder, aiming at an aircraft transponder antenna, pressing the test buttons on the outside handle, and reading the viewfinder display. Aiming of the Viewfinder is simulated using the mouse to position the cursor in the desired directional arrow, located in the upper right corner of the window, and pressing the left mouse button. The outside Test Set switches (buttons) are shown again through a port hole at the upper left of the screen. Using the mouse the user can simulate pressing the switches to perform the various tests required. LED's and lamps are simulated to display the readout that would result from the test performed.

Passive coaching is provided if the learner simply points at a viewfinder component and clicks the left mouse button. A pop-up displays appears providing information about that component to the learner. Figure 3 illustrates coaching related to the Accept Lamp that was requested by the user.

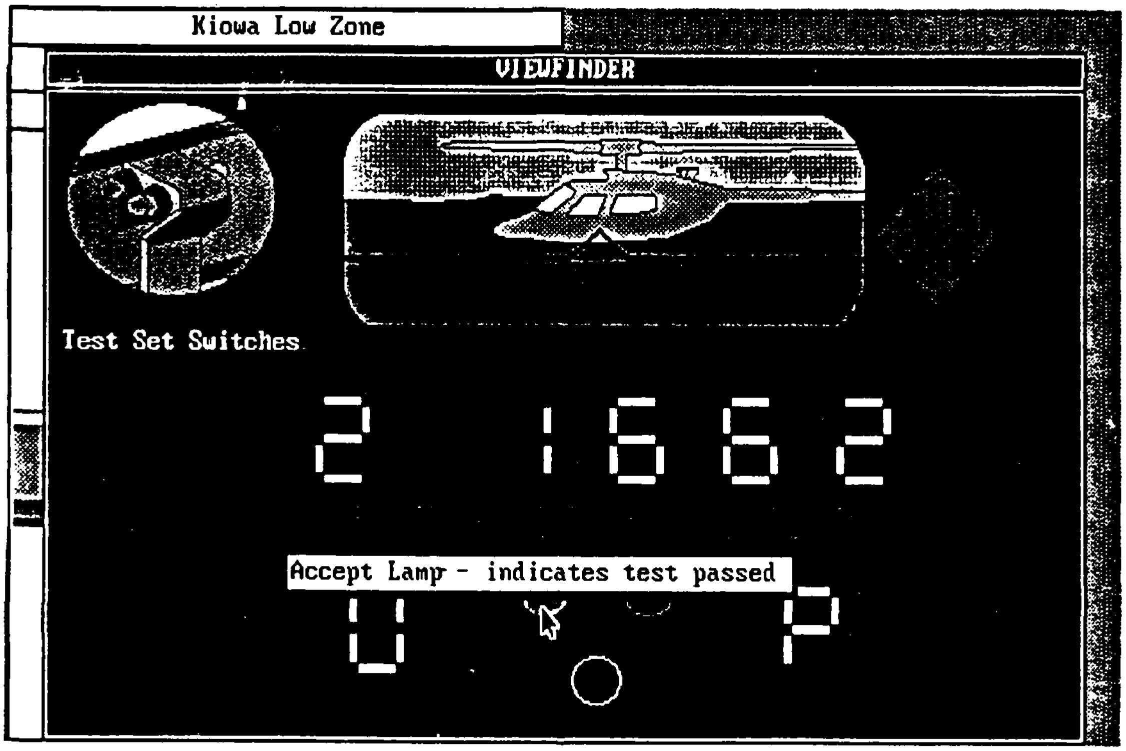

Figure 3. Viewfinder window

Correct aiming of the test set also requires the user to be positioned in a preferred test zone. If the user is outside of a test zone, the transponder antenna will be shielded from interrogation by the test set. A map of Test zones corresponding to each aircraft type is shown in a separate window. An example of the lower test zone of the Kiowa helicopter is shown in figure 4. The position of the user is simulated by a dot on this map. The learner can reposition himself on the map by pointing, with the mouse, to an area on the map and clicking the left mouse button.

The socratic tutor is provided in a separate window for the learner. The tutor provides semantic knowledge related to operation of the Test Set. From the tutor the learner is free to activate any other window in order to simulate the operations being

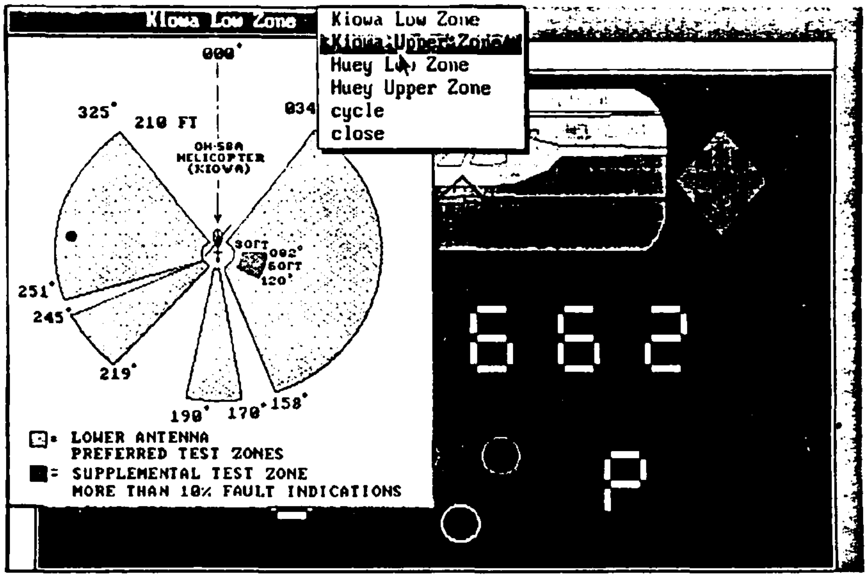

Figure 4. Test zone window

learned. Navigation through the tutor is carried out by mousing on varying selections available from the tutor windows' pop-up menu. An example of one of the tutoring screens and its corresponding menu is shown in Figure 5.

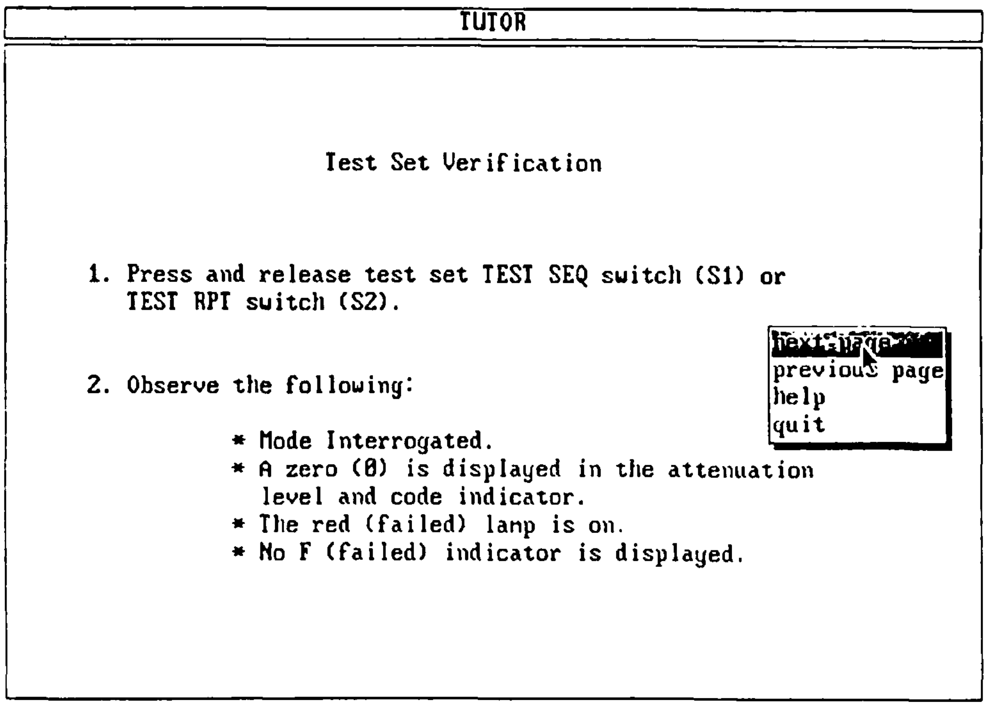

Figure 5. Tutor window

KNOWLEDGE ENGINEERING

INTRODUCTION

A variety of types of knowledge can be entered into an Intelligent Tutor. The exact nature of the knowledge required to optimize individual learning will require additional research and was not the goal of Phase I. What was desired during Phase I was to design the basic components required for entering heuristical knowledge into the system.

SOURCES OF KNOWLEDGE

A complete intelligent tutoring system requires several sources and types of knowledge. The expertise of a human expert knowledgeable in the subject matter is most obvious. A second source of knowledge for tutoring is the knowledge used by an expert human teacher. Frequently such experts have gained their skills from a combination of education and years of practical experience. Often such experts cannot articulate the path they took to their conclusions and decisions. They *chunk information* into much larger cognitive packages then neophytes. Their reasoning process has had such subtle stimulus strengthening that it appears to be intuitive.

The main sources of knowledge for the Phase I effort comprise the APM 424 student training manual, the APM 424 technical manual, and Mr. John Taylor, an Instructor for Teledyne Electronics Inc. who is experienced with the transponder test set. The information gleaned from these sources was redesigned and modified for inclusion in the IKIS project by MICROEXPERTS' instructional psychologist.

If training of field operation of the Transponder Test Set is to remain the subject domain of the Phase II effort, actual flight line functioning of the device and an experienced operator will be required. Furthermore a review of the operation of the simulation should be carried out by a technician who is completely familiar with the functioning and potential faults of the test set. Finally, student testing and revision will be required to produce the final product.

CHARACTERIZATION OF PROBLEM DOMAIN

As described briefly above, the problem domain consisted primarily of operational training and fault identification at the field level. Operation of the Transponder Test set on the flight line involves correctly performing each of the following procedures:

* Connection of the Test Set to the KIR computer cable
* Connection to an appropriate power supply
* Connection to KIR-1 computer
* Loading of Mode 4 code into KIR-1
* Loading of Mode 4 into Test Set
* Recognizing the name and function of all components
* Performing the lamp test
* Correct aiming of test set at an IFF antenna
* Stepping through the Test Sequence
* Discriminating operator faults
* Performing the test repeat function

CONCEPTS & RELATIONS FOR PROBLEM SOLVING

An aircraft transponder is designed to respond to a "query" by sending back electronic signals indicating that it is friendly. If the transponder does not work correctly, the aircraft could easily be interpreted as a foe. A properly functioning transponder is essential to the well-being and effectiveness of the aircraft and its pilot. The Transponder Test Set is designed to detect faults in the aircraft's transponder. If the Test Set has been operated correctly and is functioning properly, then a defective aircraft transponder is indicated by the readout seen in the viewfinder display.

The field operator of the Transponder test Set must learn to discriminate between three types of problems related to functioning of the Test Set. Errors can result from:

* Faults in the Transponder

* Faults in the Test Set

* Incorrect Test Set operation

It is imperative that the Test Set operator be familiar with Test Set operation, the Test Set display and the meaning of each test lamp and LED readout that can occur. This knowledge is important for proper Test Set operation and fault identification.

The Test Set fault codes are displayed in the lower right-hand corner LED of the viewfinder. Codes displayed are numbered 0 through 8, F, and A. Each code corresponds to a probable fault, usually in the transponder. Code F indicates a failure in the Test Set itself while code A indicates an angle deflection indicating incorrect operator position. The learner can review the meaning of each code from the tutor.

Faults in the Test Set are, in most cases, indicated by the BIT (built-in-test) that is performed prior to every mode test. As explained above, code "F" in the lower right-hand corner indicates a Test Set fault. This assumes that the code LED is itself operational. The operator must be sure to perform the lamp test prior to using the Test Set and at any time that a lamp or LED failure could produce an anomalous readout. The simulator simulates the functioning of the lamp test by allowing the user to click on the lamp test button using a mouse pointing device.

Faults are most likely to occur due to incorrect operation of the test set. Faults can result from performing any of the following operational procedures incorrectly:

* Aiming of the test set

* Positioning in preferred test zone

* Disconnection of KIR-1 computer and cables

* Activating test sequence and test repeat buttons

* Loading of mode 4 code into test set

The ability of the operator to identify these faults and effect the appropriate repair procedure is crucial to his function.

To test the operator's ability to diagnose faults a fault can be inserted into the Test Set or transponder from the top viewfinder menu. The user is made aware that a fault is present but the exact nature of the fault must be discovered. The learner is free to consult the tutor during this process. When identified, the fault can be repaired by mousing on the correct repair procedure from the fault repair menu.

MODELING STUDENT PERFORMANCE

No intelligent communication can take place without understanding the learner. Information about the learner and the learner's behavior is stored in the student model. The adaptability of an intelligent tutoring system is largely determined by the qualitative and quantitative student behavioral measurements contained and accessed in the model.

Observable behavior, in many cases, can have multiple sources of strengthening. The cognitive components that evoke a given behavior can only be inferred. A major goal of the Phase I research was to specify the basic components of the student model carrying out detailed Phase II research.

As currently implemented, the student model stores student performance history including the current simulation state, plus faults that have not been correctly diagnosed by the learner. These facts are added to the knowledge base during program execution. In this way the inference engine has access to facts related to the current student so that didactic decisions can be made that adapt to that student.

Most importantly, the student model provides a test bed for further research into relationships between *observable behavioral* events and inferred student cognitions. The student model, as implemented, is an object with its data and variables hidden from other objects in the systems. Additional behavioral measurements can easily be inserted along with additions and modifications in the inference rules. Performance measurements can then be used to determine the appropriateness of the inferencing being carried out.

KNOWLEDGE BASE

The knowledge base consists of facts together with rules that operate on those facts. The heuristics gleaned from a human expert or experts are captured in the knowledge base. As mentioned above, the human expertise required for an intelligent tutoring system includes both the expertise of one or more subject domain experts as well as the heuristical knowledge of an expert teacher. The implementation of this knowledge is still theoretical as well as empirical. The communications band between the user and the expert system interface is obviously narrower and quite different from the rich communication between a student and human tutor. The task of constructing a model of the learner or the expert is not a simple one for computer based systems. IKIS provides a test bed environment for empirical research into the use of simulations combined with heuristics that optimize learner performance.

KNOWLEDGE REPRESENTATION

Knowledge can be represented hierarchically as zeroth order, first order, and second order knowledge.

Zeroth order knowledge consists of the basic facts, procedures, and relationships about the subject domain. It is low level "textbook" knowledge. IKIS provides this to the user through the socratic style tutor, built in coaching mechanisms, and context sensitive help screens.

The heuristical knowledge embodying the rules of thumb and judgmental criteria of an expert is sometimes classified as the first order correction to the zeroth order factual theory and begins to lend some intelligence to the system. IKIS employs heuristical knowledge related to the faults that may occur, user induced or otherwise, in operation of the transponder test set.

A second order correction to the domain knowledge is metaknowledge, knowledge about knowledge. Such knowledge, when incorporated into the system, can provide auxiliary information to the inference engine. This information can be used to provide deeper answers to questions, restrict the search space for a solution, and control a more adaptive user interface. Implementation of metaknowledge is beyond the scope of the Phase I research. However the modular nature of the inference engine provides an easy mechanism for creating whole new instances of the rule base if desired. Research to be carried out in Phase II will focus on identifying and implementing this level of knowledge.

TASK ANALYSIS

The designers performed a task analysis to identify the nature and quantity of knowledge that can be captured in the system. This involves identification of appropriate behaviors and behavioral sequences along with the knowledge required to correctly operate the Transponder Test Set.

TERMINAL OBJECTIVES

Army training objectives related to the Transponder Test Set requires that, without the aid of notes, using only supplied operators manual, the student will be able to perform/describe, orally or in writing, the following:

* Purpose of the AN/APN-424(v) 2 Transponder Test Set.

* Unpacking/Preparation for use.

* Operational Characteristics of the TS-4077/APM-424(v) 2.

* Analyze Display of the TS-4077/APM-424 (v)2.

* Testing IFF Systems with the TS-4077/APM-424 (v)2.

* Operator Corrective Action/Unit Level Maintenance Steps.

IKIS designers identified a subset of these objectives that were rewritten in the form of behavioral and cognitive objectives.

BEHAVIORAL OBJECTIVES

The Phase I project concentrated on operation and fault diagnosis of the Test Set. Unpacking and preliminary preparation procedures were not included. Following completion of IKIS the student should be able to:

* Recognize and describe the names and functions of all test set switches, viewfinder LED's and lamps.

* Correctly recognize and interpret any and all possible viewfinder displays.

* Correctly aim the test set at aircraft IFF antenna.

* Identify and list the correct steps required to load mode 4 code into the test set.

* Using the simulator, perform the lamp test and test set verification procedures.

* Connect and disconnect KIR-1 computer, cables, test set, and power supply, using the simulator.

* Recognize and indicate the correct repair or replacement procedure when a fault occurs in the test set, transponder, KIR-1 computer, or cables.

COGNITIVE OBJECTIVES

Beyond teaching of rote behavioral responses, the system should teach a higher level of understanding of the procedural and factual relationships between component parts of the learning tasks. Cognitive theory suggests that knowledge is first acquired declaratively through instruction, and that it has to be converted and reorganized into procedures through experience. IKIS combines Socratic style tutoring and coaching with simulation to help strengthen and exercise cognitive components of the subject domain and enhance the learners' awareness of their own abilities and confidence in the use of the field unit. Specifically IKIS cognitive objectives include:

* Conceptualize relationships that exist between transponder faults, test set faults, and user induced faults.

* Integrate factual components related to test set positioning and aiming with corresponding display readouts and and system faults.

* Internalize procedural methods required for Test Set verification and operation and there relationships with Test Set display characteristics.

TEACHING STRATEGIES

Adding the knowledge of an expert teacher to provide an adaptive tutoring system requires the design and implementation of an overall teaching strategy. Creating this level of knowledge (metaknowledge) was not a goal of the Phase I research. However since this is a goal of the IKIS project, the implementation had to be considered in the system design. The major components of the IKIS design strategy are described below.

MEASURING BASELINE PERFORMANCE

Measuring a learner's entering domain related performance skills is necessary for the tutor to adapt to the individuals needs. Once the cognitive and behavioral objectives have been defined, the relative strength of responses related to those objective can be measured under appropriate stimulus conditions. Pretesting the learner with questions related to the learning objectives is a useful, but not necessarily sufficient, method of measuring this baseline.

Historically, many student who perform well on written exams still cannot perform well on related tasks. This is not surprising, since the stimuli that evoke the responses are, in fact, very different. The learner has had little chance, or help, in resorting the cognitive components of the task being taught. High fidelity simulation provides a stimulus situation more closely related to the stimuli which ultimately will evoke appropriate responses.

The simulation implemented in the Phase I prototype provides an environment for measuring baseline behaviors under stimulus conditions more closely related to those of the operational environment. IKIS can simulate complex situations that require the discrimination of a variety of stimuli and the integration of system functional relationships for the operator to respond appropriately. Fault identification, for example, requires understanding system operation as well as integration of relationships between positioning and aiming the test set, loading of system codes, and viewfinder display codes. During Phase II behavioral measurements of operator performance related to a complex task as well as each component of the task will be made. Such measurements reflect both the cognitive and behavioral performance of the individual learner.

SUCCESSIVE APPROXIMATIONS AND SMALL STEPS

The system reaches its behavioral objectives by reinforcing successive approximations toward the desired behaviors. A stimulus is presented that provides an occasion upon which the learner is likely to respond appropriately. Responses are then compared to baseline measurements. Those that are successively closer to the desired behaviors are strengthened by reinforcement. Initially stimuli presented to the learner should be designed so that the learner can easily discriminate it from the background noise. Once the desired response has been sufficiently strengthened, the discriminative stimulus is gradually faded until it takes on those properties that approximate real world stimuli as closely as possible.

IKIS is designed to provide appropriate stimuli through the Socratic tutor, coach, and simulator. In the Phase I prototype the user is directed, in small steps, to perform each task related to Test Set operation. Help is available from the tutor, coaching, and simulation to help identify system components and clarify procedures. Natural reinforcers associated with successful operation and correct functioning of the the Test Set are available through the simulation.

As metaknowledge is added to the system during Phase II, stimuli appropriate for learning higher order knowledge in small steps will be added to the system. Stimuli that the learner should discriminate will be displayed initially at full intensity while non related stimuli can be diminished in intensity. For example a fault due to incorrectly aiming the Test Set will result in faulty data being displayed by one or more of the LEDs'. By diminishing all display components except for the aim and the appropriate LEDs', the user will more easily discriminate those stimuli from the background. Coaching will help provide additional supportive semantic knowledge related to the functional relationships producing the faults. As the users' accuracy at identifying and correcting this fault increases, the differences in stimulus intensity from the background will be decreased. In this way the student will gradually learn to make the correct discriminations related to identification of that fault.

IMMEDIATE FEEDBACK

Immediate feedback following learner responses has been shown to be an important and powerful teaching tool. Choosing the appropriate

moment and form of feedback is critical to the learning process. Feedback that appears, to the system designer, to be reinforcing may prove to be neutral or even punishing to some learners. Reinforcers are determined by their effects on the learner, not the teacher. The quality and quantity of feedback useful for maximizing the learning process will very from individual to individual and lesson to lesson. This is another area in which the system must adapt to the learner.

Tasks that have complex behavioral and cognitive components often occur in sequences. Under such conditions responses at one point of the sequence serve as stimuli for the next chunk of cognitive and behavioral events. Immediate feedback provided for a response in the sequence can disrupt the sequence, be punishing to the learner, and detrimental to the overall learning process. Small errors on the part of the learner may not be significant enough to warrant stopping the simulation to provide immediate feedback. In such cases it is better to provide a less intrusive means for the learner to discriminate self errors. Icons and/or symbols can be displayed when and where the error is detected to flag the learner of an incorrect response.

The IKIS Phase I project provides feedback primarily through the coach. As mentioned above, passive feedback is available to the user for discovering functions of the viewfinder components including the LED's and display lamps. Active feedback is demonstrated when an error *in disconnection of the KIR-1 computer* is made by the learner. This is a sever enough error that the student is briefly interrupted and told of the error. The student is, however, free to continue with the simulation once they have acknowledged the error.

As metaknowledge is added to the system during Phase II a more adaptive feedback mechanism will be implemented. The system design calls for using behavioral measurements as an indicator of the effectiveness of the feedback provided. In addition, as global statistics of all users are collected the system will learn to be more adaptive to specific types of learners and specific types of problems.

SYSTEM ARCHITECTURE

IKIS is composed of five major components; the user interface, tutor, simulator, student model, and inference engine. The diagram shown in figure 6, below, illustrates how these components are related.

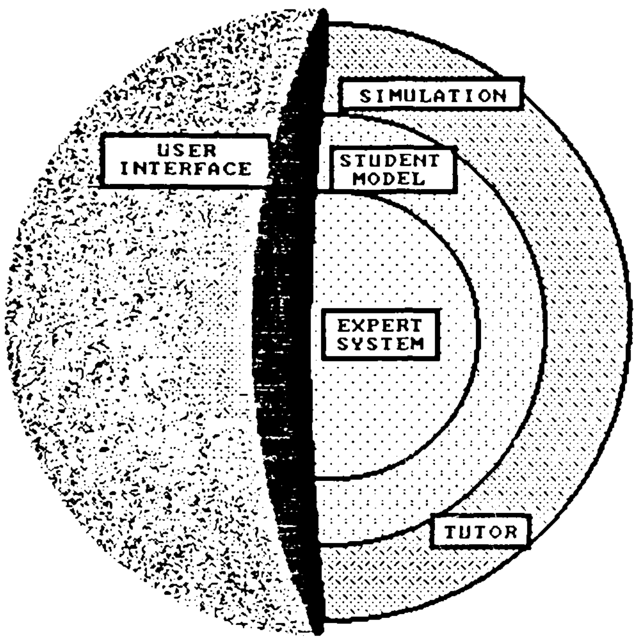

Figure 6. System Architecture

The prototype software was developed using the Smalltalk V language. Smalltalk is an object oriented language that supports mouse input and high resolution color graphics compatible with an IBM Enhanced Graphics Adapter.

The IKIS Phase I project produced almost 1 megabyte of high resolution color graphical images and 100 Kilobytes of Smalltalk source code. The Smalltalk image, consisting of all Smalltalk classes plus IKIS object source code is approximately 1.2 Megabytes

in size. The frequent swapping out of Smalltalk objects to disk decreases the processing speed of IKIS. Currently a version of Smalltalk that utilizes the expanded memory of the IBM AT is being beta tested by this company. When complete this version should execute all IKIS code without the need to swap out objects, dramatically increase the speed at which IKIS operates.

USER INTERFACE

IKIS employs a high fidelity color graphics interface. Functional components of the program run independently in separate windows on the display. A mouse pointing device handles almost all input from the user. User input and system navigation occurs through the selection of options displayed in pop-up menus. Each window has two or more pop-up menus. One is associated with the top I bar of the window. The second is associated with the window pane itself.

A menu is activated by pointing to the position described above and pressing the right mouse button. Once the menu is active, choices on the menu are highlighted by moving the mouse forward or backward in the menu. Once a choice is highlighted, it can be activated by pressing the right mouse button. An inactive window can be activated by selecting the "cycle" option in the I bar menu or by simply pointing in one of the background windows and pressing the left mouse button. Selecting "help" from a pop-up menu will activate the tutor window and display a context sensitive help screen.

TUTOR

IKIS provides tutoring capabilities through a Socratic Tutor and a Coach. In addition the simulator and coaching mechanisms provide learners with a discovery mechanism through which they can by exploring system components, functions, and relationships. Context sensitive help is available from most system menus.

Socratic

The tutor is evoked from the top menu of the viewfinder or by mousing on the tutor window. In addition special tutoring screens are activated when the user requests help from other system windows.

The Socratic Tutor provides zeroth order textbook knowledge to the student in a separate window on the display. Designed as a finite

state system, the tutor displays separate instances of the state object. This design creates handy mechanisms for adding and updating semantic components and their links to other learning states and releases the code from order dependence.

Each tutoring state contains transition rules that determine what the next state will be based on user input. The state system tutor design forms a core element in the development of an expert tutor authoring system. In later phases, the designers can implement an editor for easily creating states and their links and reducing the cost and complexity of authoring new lessons.

Coaching

The coaching mechanism provides an additional means of tutoring. The system supports both passive and active coaching. Passive coaching is used for identification of components of the Test Set. Using the mouse to point the cursor at a lamp, LED, or other component of the viewfinder results in a description of the device being displayed.

Active coaching begins the moment the learner incorrectly performs a procedure. An example of this has been implemented in the Phase I prototype. If the KIR-1 computer is not disconnected in the correct order loss of the mode 4 code can occur. IKIS interrupts the student when this error is detected and coaches the student, describing both the error and correct procedure.

Additional active and passive coaching will be provided in Phase II as higher levels of knowledge are added to the knowledge base. This is one way in which the system can become more adaptive to individual learners.

Discovery

Discovery learning results from using experimentation with the components of the simulator and requests for deeper levels of knowledge about component and functional relationships. Passive coaching, a component of discovery learning, provides requested information to the learner about the components being experimented with. In Phase II, deeper levels of knowledge will be added to the coaching mechanism to provide greater breadth to this component.

SIMULATION

The simulation of Test Set functional operation is a major component of IKIS. From the Test Set window the learner can simulate the procedural components related to connecting the KIR-1 computer and cables to the Test Set and power supply, loading mode 4 into the KIR-1 computer and disconnecting the KIR-1 and cables. These concepts and procedures can then be cognitively assembled by the learner.

The component parts of the simulation include the viewfinder window, LED',s test lamps, Test Set, switches, KIR-1 computer, cables, test zones, and the helicopters. All are represented as objects in the system. The current state of the simulation is changed and updated by messages sent to these objects from the inference engine. The knowledge base contains facts related to current inputs affecting the state of the simulation. A change in the facts related to the simulation results in a change in the current simulation state.

The viewfinder window is a major component of the simulation. Looking through the viewfinder the learner can simulate aiming the test set at the aircraft IFF antenna. The viewfinder sight must be lined up within 5^{o} of the aircraft's IFF antenna for correct operation. The learner aims at the antenna by pointing and clicking the mouse in the directional arrows to the left of the sight. A simulation of the viewfinder's LEDs and test lamps is also provided. The inference engine sends messages to update these LEDs and lamps. The simulation displays readouts similar to those that would be obtained in actual use including erroneous data if the Test Set is operated incorrectly.

Preferred test zones are shown in the test zone window. The learner positions himself anywhere on the test zone map by pointing and clicking with the mouse. His position is indicated by a red dot displayed at that position. The helicopter, shown through the display, will change its position relative to the position the operator has chosen in the test zone. Whether or not the operator is correctly positioned in a preferred test zone is a fact sent to the fact base and used by the inference engine to control functioning of the test set objects.

Test Set switches on the handle of the Test Set are shown through a porthole in the upper left of the viewfinder window as well as in the outside view of the Test Set. Pointing and clicking with the mouse simulates pressing the switches. The switch "pressed" is indicated as a fact added to the fact base. The inference engine, upon scanning the fact base, updates the state of the simulation. The fact is then removed from the fact base until the switch is pressed again.

The outside view of the Test Set is shown in a separate window. Selections shown on a pop-up menu allow the learner to simulate connecting (or disconnecting) the Test Set to the KIR-1 computer, connecting cables, and to a power source. The menu also provides for simulating the loading of mode 4 codes into the KIR-1 computer. Facts are added or removed from the fact base related to the state of each of these components.

Use of the simulator provides the learner with the chance to integrate both behavioral and cognitive, procedural and factual components of test set operation. This provides a deeper level of learning then is possible through reading the instructional manual alone.

STUDENT MODEL

The student model is a separate object in the system that stores facts about each individual student. When a new student first uses the system it creates a file containing an instance of this object. As the student interacts with the system, the student model maintains information about the current state of the simulation. The students file is updated by storing the updated instance on disk as the student exits the program. Upon reentry, the student returns to the state of the simulation when last used.

Each instance of the student model is initialized with a list of possible faults that may result through an error in the transponder, the Test Set, or due to operator error. The fault list is currently arranged in an increasing order of difficulty of diagnosis. When the fault has been inserted, the student may identify the fault and then indicate the appropriate corrective action. Then the fault is removed from the student's fault list. If a fault is not correctly identified the student may still remove it. However then the fault is returned to the students fault list.

Further development of the student model during Phase II will increase the ability of the system to adapt to the individual student. This is an area of exciting cognitive and behavioral research. Performance measurements related to accuracy, response latency, and frequency collectively reflect the learners cognitive processing of information. The IKIS Phase I project provides an environment for empirical testing of relationships between system motivational components, student performance, and cognition.

INFERENCE ENGINE

The heuristical knowledge of both domain experts and an expert teacher is stored in the system inference engine. The engine operates on facts provided to it by other objects including the simulator, tutor, and student model. The fact base is designed as a global dictionary to which facts can be added or removed, based on system activity and user interaction. The inference engine implemented in Phase I is forward chaining. Each rule in the inference engine consists of one or more facts which, if true, cause some action to occur. One possible action that may occur when a rule is fired is the production of a new fact. Therefore when the inference engine is evoked the rule base is scanned repeatedly until no rules are left to fire.

Continued research and development during Phase II will focus on adding to and refining the inference engine and rule base to provide higher orders of knowledge, including metaknowledge, and more sophisticated reasoning. Interactions between the inference engine and facts provided by other system objects, especially the student model, will be the key to full development of an adaptive ITS.

CONCLUSIONS

Phase I of the IKIS project has produced the elements of a sophisticated simulation-based intelligent tutoring system. Its student model, teaching strategies, and discovery system can be extended into a fieldable and cost effective tool.

Moreover, the modular design of IKIS makes such extension possible. Each system component can be modified and revised independent of other modules in the system. States can be augmented, modified, or deleted from the tutor with ease. Tools to measure and record learner behaviors easily can be added to the student model. Additional facts can be incorporated readily into the fact dictionary from the student model and simulation. Even components of the simulation can simply be modified and changed as needed.

In addition the results of the Phase I project suggest approaches and tools for research into relationships between learning, cognitive load, and performance. The subject domain of the Phase I research did not place a severe enough cognitive load on the learner. Hence it may be necessary to apply IKIS to a more sophisticated training problem to provide sufficient cognitive and behavioral requirements for meaningful future research.

Simulation based intelligent tutoring systems ultimately can provide more efficient and effective training of complex tasks than conventional methods. Furthermore it can provide a more objective analysis of individual user aptitude and performance than has been possible with other techniques. The IKIS Phase I project provides a test bed for further research and development of simulation based training for ever more sophisticated military and industrial equipment.

RECOMMENDATIONS

The training and measurement of cognitive skills related to real time decision-making is an area in which simulation based intelligent tutoring systems like IKIS can have a significant effect. Other research by MICROEXPERT suggests that in similar tasks such as intelligence message routing and missile radar training, teaching of semantic knowledge must be supplemented by syntactic approaches. "Doing" in such tasks becomes the measure of "knowing."

The personnel who currently teach and grade this type of performance training cannot always provide a consistent quality of training or sufficient objective analysis of learner performance. Research during Phase II should focus on teaching real-time cognitive skills through measurable results and student performance analysis for increasingly complex tasks.

Hence, research and development during Phase II should concentrate on measuring and training individuals in tasks having complex cognitive and behavioral performance components. In particular the Phase II project should focus on the following:

1. RESEARCH ON TEACHING STRATEGIES AND METHODS. Communication to the learner is based on using interactive simulation to encourage a semantic rationalization process. The simulation provides an interactive diagnostic tool for constant evaluation of the learner. The relationships between observable and quantifiable behavioral sequences and cognition should be studied further. This data can be used for developing didactic operations and plans of action by the system.

2. IMPLEMENTATION OF DEEPER KNOWLEDGE. Data gained from research described above will result in additional types of knowledge, especially metaknowledge, that can be added to the inference engine. This knowledge will be useful in allowing the system to adapt to individual learners and maximize learner performance.

3. AUGMENTATION OF SYSTEM INTELLIGENCE. Features to be added to the inference engine include backward chaining, use of global variables, adding conflict resolution (tie-breaking) procedures. Other enhancements will also be reviewed for possible adoption.

4. ADDITION OF RECORD-KEEPING MODULE. Student performance records should be available for viewing by superiors, trainers, and the learner as a means of system refinement and as a tool for evaluating the learner.

5. ENHANCEMENT OF KNOWLEDGE REPRESENTATION. Techniques to organize knowledge into data structures for system manipulation should be further developed. Task analysis is an important step not always utilized in the developing of a knowledge base. Building on the task analysis completed during Phase I, additional diagnostic rules and causal relationships should be added to the knowledge base. The knowledge base can then be used to generate an "expert's solution," which when compared to the student behavior, provides a basis for advising the student.

The MICROEXPERT design team has attempted to cut development time and the cost to bring up a new tutor by attempting to keep the components of the system modular. By maintaining modularity, it should be possible to create new tutors for related domains of training with reduced effort. While changes and additions to system components are required, tutoring control and the basic components of the student model and inference engine can be retained and built upon.